Available online at www.sciencedirect.com

SciVerse ScienceDirect

ELSEVIER

Physics Procedia 36 (2012) 1189 – 1194

Physics Procedia

Superconductivity Centennial Conference

Analysis of magnetic remanence calculated in HTS by pulse magnetization process taking into account the temperature effect.

López, J.[a], Maynou, R.[a], Granados, X. [b], Grau, J.[a], Bosch, R.[c], Chia-Hao Hsu[d]

"a EUETIB (UPC-BarcelonaTech), Urgell 187 Barcelona 08036 Spain"
"b ICMAB , Campus UAB Cerdanyola del vallés, 08290, Barcelona Spain"
"c ETSEIB (UPC-BarcelonaTech), Diagonal 649, Barcelona 08028 Spain"
"d Departament of Engineering, Cambridge University, Trumpington Street, CB2 1PZ UK"

Abstract

Multiple studies have reported information about the magnetization by pulses applied in YBCO superconducting pellets. “Electrical machines” is one of the areas where it is possible to take advantage of using superconducting magnetized pellets by the high magnetic trapped field. However, it is well known the strong dependence of the maximum value of remanence with temperature. The relaxation experienced by the HTS, once the pulse magnetization has finished, and the heat generated in the superconductor by the effect of the “supercritical” currents generated during the flux penetration, make the maximum trapped field lower than expected considering a critical state model. In this work we present simulations performed, with a commercial finite element program, about the resulting magnetization in the HTS superconducting pellets, taking into account the influence of temperature.

"Keywords: pulse magnetizastion, trapped field, magneto-thermal simulation"

1. Introduction

Engineering applications use normally simulations programs to know the behavior of materials, and components before to begin a production of a new product. Superconductivity field has each time more informatics tools that can help us to study how superconductor acts in the devices where they are included. The programs of modeling based in FEM analysis are a big help to determine the behavior of the superconductor materials. In our case, we try to extract information about what is the behavior of the

1875-3892 doi:10.1016/j.phpro.2012.06.200

superconducting material, as a pellet, in a magnetization process. In some cases, the FEM analysis only has into account the electromagnetic study, but when the currents that are flowing inside the HTS bulk are higher, it is generated heat energy in the pellet, his temperature increase and the material properties changes faster in time. For this reason, is adequate to include thermal analysis in the electromagnetic simulations.

2. Magneto-thermal analysis

Some authors [1], [2], [3], [4], [5], [6], [7] have made interesting simulations of magnetic fields applied over a superconducting pellet and discusses about how the currents densities are generated and distributed into the superconductor. Relaxation process due to thermal effect is a phenomenon that should be taken into account. The relaxation process is a natural evolution of the superconducting pellet when the induced current densities increase J_c value. Is well-know that J_c has temperature dependence like J_c= a-bT^2 (a, b constants). The energy generated during the magnetization is transformed in heat that increases the temperature of the pellet, and consequently the effective reduction of J_c value. This effect makes that relaxation process concluded at fewer values that expected only with electromagnetic relaxation.

Figure 1 shows the results of a 2D simulation by FEM analysis [8]. The simulation corresponds to a pulse magnetization process. The pulse is 10 ms longer and is generated by a three-phase copper winding with a magnetizing current density of $8.6 \cdot 10^4$ A/cm^2.

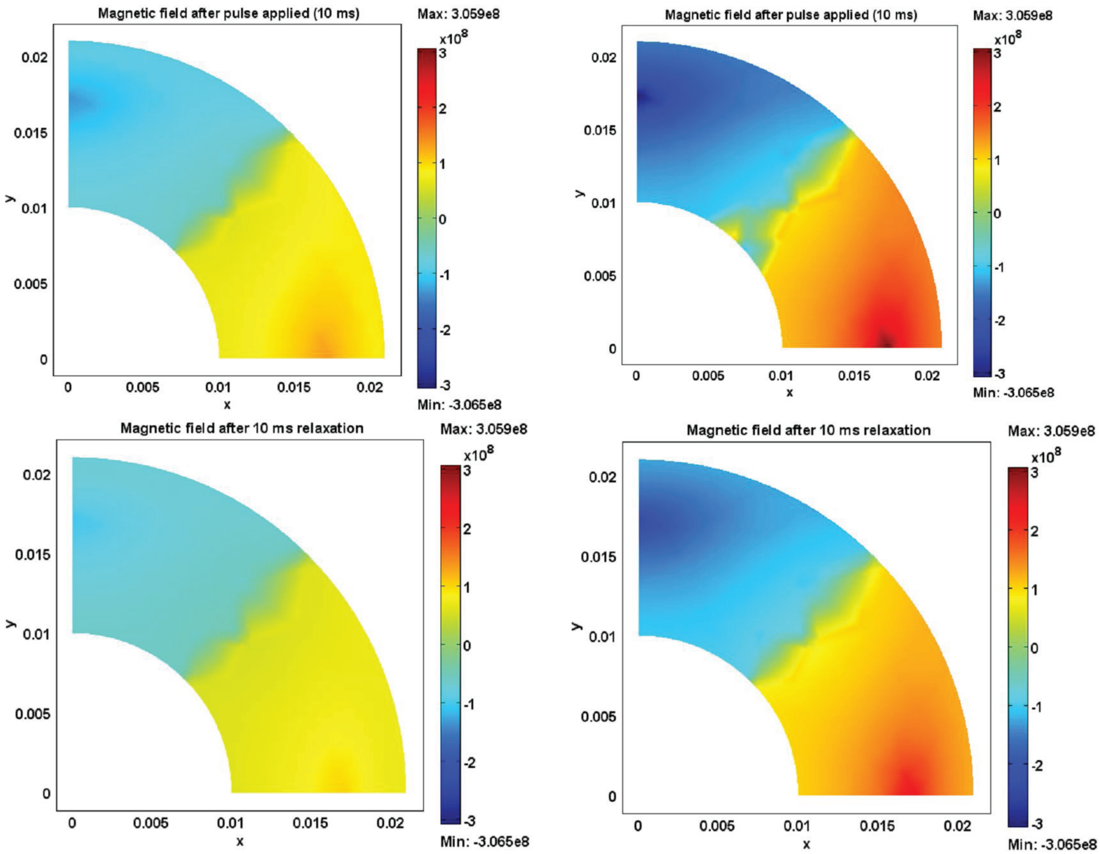


Figure 1: Current density

Figure 1 shows the results of a 2D simulation by FEM analysis. First row correspond to current density obtained after apply a 10 ms sinusoidal pulse magnetization. Second row correspond to current density obtained after 10 ms of relaxation after the pulse finish. The levels of the color legend are the same for all the pictures in Figure 1

In first row is evident the difference between two pictures. Right picture is the result of only FEM electromagnetic analysis. Left picture is the result of two FEM analysis that has made together; thermal and electromagnetic.

Despite any picture have a homogeneous color, is possible to conclude that they have a difference of values near to a factor 2.

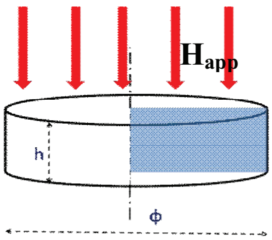
3. Axisymmetric analysis

One of the problems to affirm or accept that electromagnetic-thermal simulation are better than electromagnetic analysis is present when the system to study is only a design and we don't have possibilities to compare experimental with simulation data.

To avoid this situation we make a simulation of a cylindrical pellet. Make profit of an axisymmetric analysis from a commercial software.

The model that we follow is the H formulation in cylindrical coordinates. This model was adapted by our college Chia-hao Hsu to cylindrical spatial coordinates. The supposed approximation in the model has been that, total current in the pellet is composed by planar currents loops that are perpendicular to axial dimension.

We analyze a pulse magnetization process over a cylindrical pellet with h = 11,5 mm high and diameter φ= 32,5 mm. We suppose that pellet will be magnetized by a sinusoidal magnetic field whose direction is perpendicular to a circular face.



The pulse applied has a duration of 30 ms and we leave the system relaxing for a 60 ms before to make the next pulse.

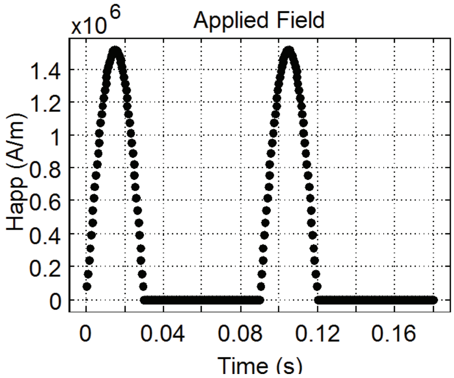


Figure 2: Magnetizing pulses applied

We make some simulations where the initial working temperature is T_0 = 20 K, 40 K and 60 K. We suppose that the pellet have this initial temperature T_0 and is surrounded by hydrogen as a cooling fluid as the same initial temperature (T_0).

If we make some simulations with different values of initial temperature, we obtain a sequence of profiles of magnetic field of different maxim values.

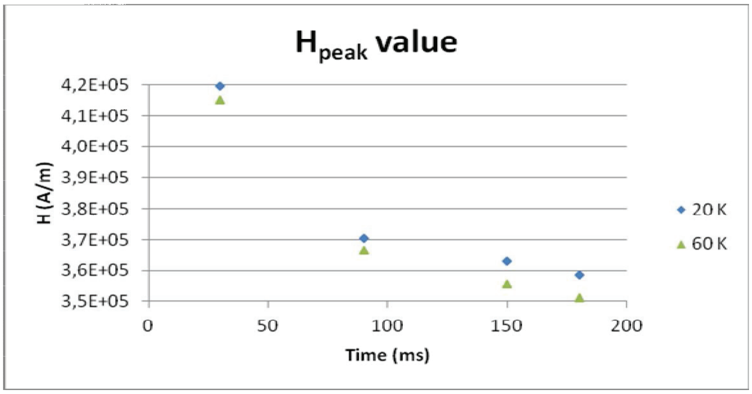
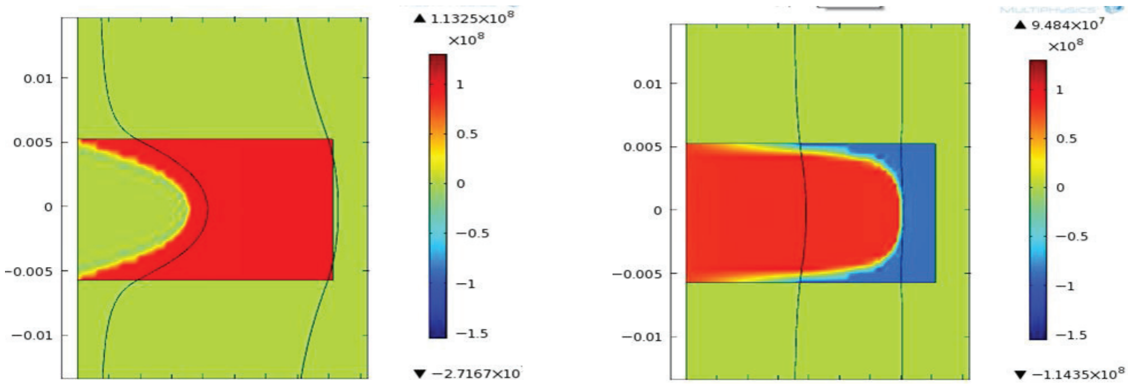


Figure 3: Distribution in time of a maximum trapped field in the pellet

Is possible to show that the second pulse not increases the trapped field,

The current density obtained in the simulation with T_0 = 40 K at the times: t = 2 ms, 20 ms, 30 ms (end of first pulse), 90 ms (end of first relaxation period), 120 ms (end of second), 150 ms and 180 ms (end of second relaxation period) are showed in Figure 4



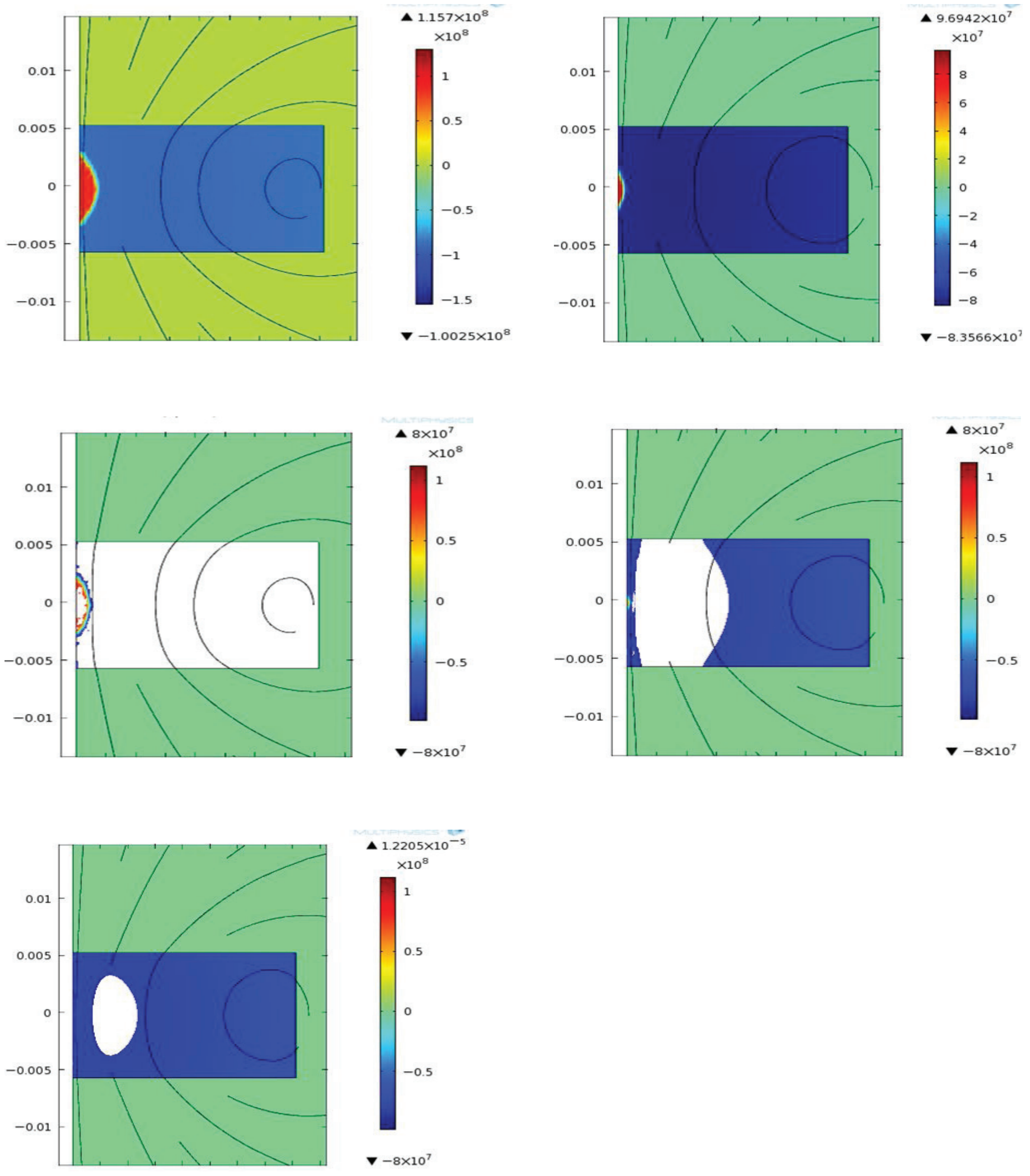


Figure 4: Distribution of J in different times after magnetizing pulses are applied

In the last three pictures of figure 4 can show in white color the zone when J is higher than J_c. The relaxation process makes the currents will decrease. But curiously, it seems that the higher current densities are not at the outside part of the pellet, but are located in the central area of the pellet, near to her axis. These kinds of results are quite different than the obtained in 2D simulations where it is assumed that the third dimension is infinite [2], [8]

4. Conclusions

Axisymmetric system can be used to modelize a HTSC superconducting pellet. Temperature effect must be taken into account to determine the magnetization of the pellets. The value of maximum magnetization depends of the Temperature.

To magnetize superconducting pellets, by ZFC successive pulses process, is not essential to make some successive high pulses. If first pulse is high enough, no more pulses are necessary. The maximum trapped magnetic field after pulse applied, decreases because of thermal relaxation effect.

Trapped magnetic field diminishes until current density generated in HTSC is higher than Jc. Successive pulses with growing amplitude make magnetizations with less heating in the pellet.

References

[1] Sander M. Geometry effects in the pulsed magnetization of high-temperature superconductor bulks parts. Superconductivity Science and Technology 2005; **18**;S63-S66

[2] Hong Z, Campbell A M, Coombs T A. Computer modeling of magnetization in high temperature bulk superconductors. *IEEE Transactions on applied superconductivity*;2007; vol 17 no 2

[3] Campbell, A M. A new method of determining the critical state in superconductors. Superconductivity Science and Technology 2007; **20**;292-295

[4] Commb T A, Hong Z, Zhu X, Krabbes G. A novel Engine for magnetizing superconductors. Superconductivity Science and Technology 2008; **21**;034001 (7pp)

[5] Navau C, Sanchez A. Current and field penetration in a supeconductor in the field of a permanent magnet. *IEEE Transactions on applied superconductivity*; 1999; vol 9 no 2.

[6] Grilli F, Brambilla R, Martini L, Sirois F, Nguyen D N, Ashworth S P. Current Density Distribution in Multiple YBCO Coated Conductors by Coupled Integral Equations. . *IEEE Transactions on applied superconductivity*.; 2009; vol. 19, no. 3, pp 2859-2862.

[7] Sirois F, Grilli F. Numerical Considerations About Using Finite Element Methods to Compute AC Losses in HTS. . *IEEE Transactions on applied superconductivity; 2008;* vol. 18, no.3, pp. 1733-1742.

[8] López J, Maynou R, Granados X, Torres R, Bosch R. Magnetization of superconducting pellets in highly inhomogeneous magnetic field. *IEEE Transactions on Applied Superconductivity* 2011;21:2295-2299